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National Uranium Resource Evaluation

ELKO QUADRANGLE NEVADA AND UTAH

Uranium Services Company
Reno, Nevada

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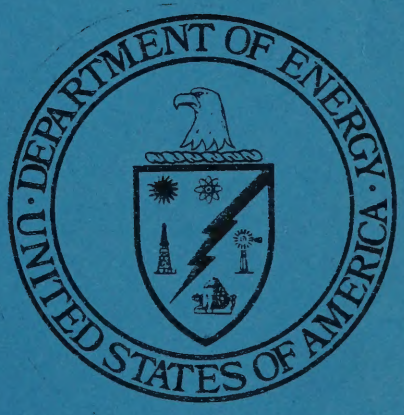

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NATIONAL URANIUM RESOURCE EVALUATION
ELKO QUADRANGLE
NEVADA AND UTAH

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1450 E. Second Street
Reno, Nevada 89502

Work performed under Bendix Field Engineering Corporation,
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GRAND JUNCTION, COLORADO 81502

This is the final version of the subject-quadrangle evaluation report to be placed on open file. This report has not been edited. In some instances, reductions in the size of favorable areas on Plate 1 are not reflected in the text.

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ABSTRACT

The Elko Quadrangle (1° X 2°), Nevada and Utah, was evaluated to identify and delineate geologic environments favorable for the occurrence of uranium deposits. Geologic reconnaissance, radiometric surveys, and geochemical sampling programs were carried out in all identified environments in the quadrangle. Known and newly identified uranium occurrences were evaluated. All geologic environments, both favorable and unfavorable for the occurrence of uranium, were evaluated and compared to analogous environments known to contain uranium deposits.

This study concludes that tuffs and sediments of the Humboldt Formation are favorable for initial-magmatic and sandstone uranium occurrences. Contact metasomatic and allogenic environments developed within the Park City limestones adjacent to the Delcer Buttes quartz monzonite are also favorable for uranium concentration. With the exception of unevaluated basins adjacent to possible igneous source rocks, all other identified geologic environments are considered unfavorable for uranium deposits.

INTRODUCTION

PURPOSE AND SCOPE OF STUDY

The Elko Quadrangle, in northeastern Nevada and western Utah between latitude 40° and 41° and longitude 114° and 116° (Fig. 1), was evaluated to identify geologic units and delineate areas that exhibit characteristics favorable for the occurrence of uranium deposits.

Geologic environments were evaluated on the basis of surface investigations and limited subsurface data. Each geologic environment was designated as favorable, unfavorable, or unevaluated for uranium deposits. A favorable environment is one that may contain or is known to contain a uranium deposit of at least 100 tons U_3O_8 with an average ore grade of 0.01% U_3O_8.

Recognition criteria of Mickle and Mathews (eds., 1978) characterize geologic and geochemical environments for specific types of uranium deposits throughout the world. These criteria are used extensively as comparative guidelines for the determination of favorable and unfavorable uranium environments in the Elko Quadrangle.

This study was conducted by Uranium Services Company under subcontract to Bendix Field Engineering Corporation (BFEC) for the National Uranium Resource Evaluation (NURE) program, managed by the Grand Junction Office of the U.S. Department of Energy (DOE).

Twenty-one (21) man-months were spent on the project, which began in March 1979 and which ended in March 1980. The initial three months were spent reviewing previous work, plotting reported uranium occurrences and radioactive anomalies, and preparing a work plan delineating the procedures, areas of interest, and approximate time table for the investigation. Field work consumed 15 months and was performed by two field geologists. Approximately 3 man-months were spent in compiling, plotting, and evaluating the data and in preparing of the final report.

Field work on the Wendover Air Force Range and numerous private ranches along the Ruby Mountains and East Humboldt Range was prohibited, and only portions of these areas were evaluated.

PROCEDURES

A literature and map study was undertaken to delineate areas of uranium favorability in preparation for the field work. Surface geologic investigations included examination and description of known uranium occurrences reported in the U.S. Atomic Energy Commission Preliminary Reconnaissance Reports (PRR's); geological, geochemical, ground and airborne radiometric surveys in geologic environments potentially favorable for uranium; and radiometric and geochemical reconnaissance of all other major geological environments.

Field data consisted of radiometric surveys (ground and airborne) and reconnaissance and detailed geologic and geochemical maps of potentially

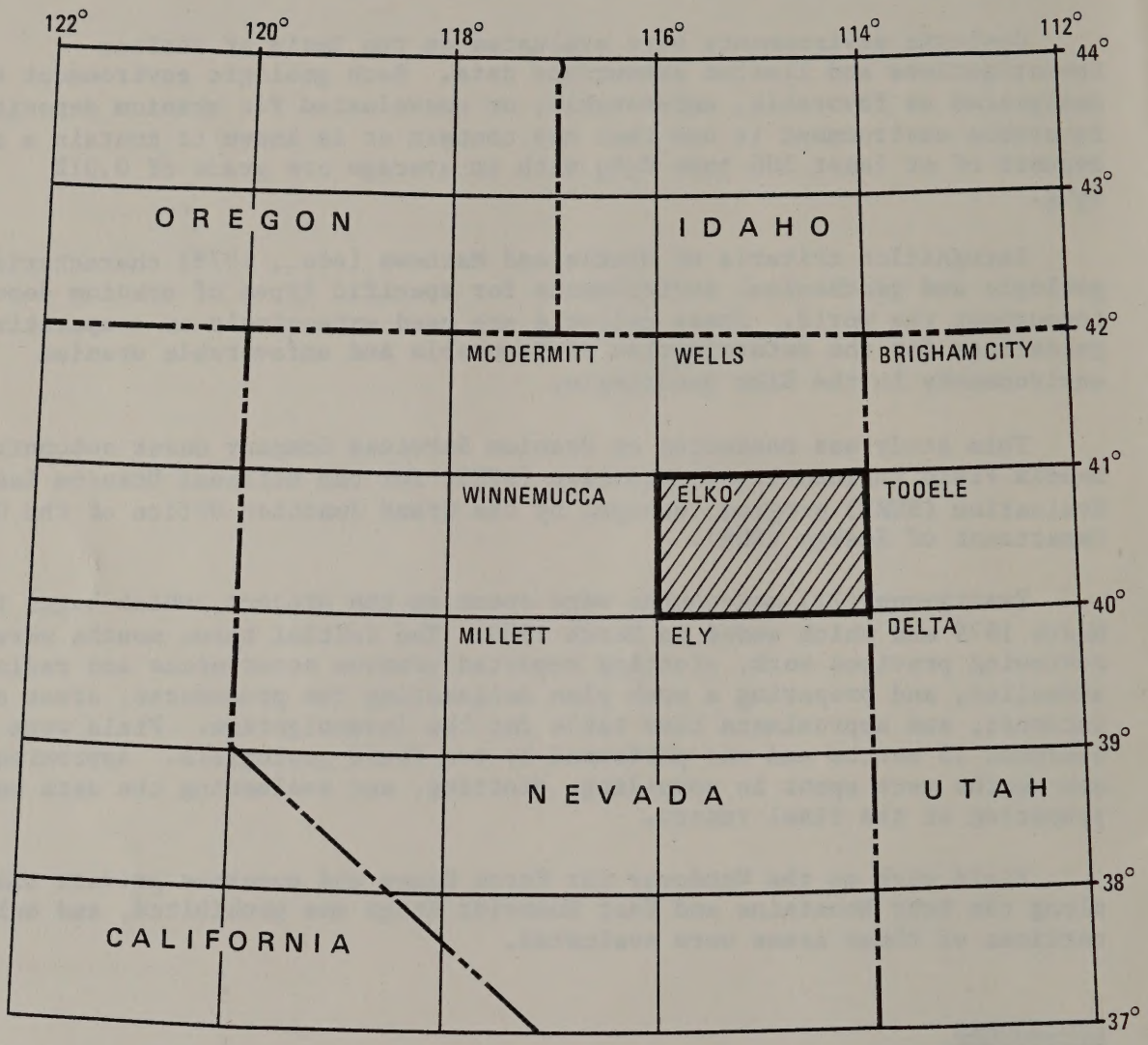

FIGURE 1. *Location of Elko Quadrangle*

favorable areas. Analytical data incorporated chemical, gamma-ray spectroscopic, and petrographic analyses of rock, soil, stream-sediment, and water samples. Gamma-ray spectrometric data were collected in the field at various sample sites; uranium values obtained will be designated by eU_3O_8.

Geochemical samples in the quadrangle consist of 446 rock samples collected from various outcrops. In addition 131 stream-sediment samples, 85 soil and 47 water samples were collected to improve the evaluation. Plates 3 and 4 show sample locations, and Appendix B lists analytical results. Most samples were grab samples and were collected to characterize the uranium content of major and minor rock units exposed in the quadrangle. Emission spectrographic analysis was performed on selected samples from rock units appearing favorable for uranium concentration to further characterize these environments with pathfinder elements.

Sample preparation and chemical analyses were performed by Rocky Mountain Geochemical Corporation, Reno, Nevada. They report that rock samples were subjected to a total digestion procedure, and total-uranium (reported as U_3O_8) contents were determined by fluorometric analysis. Emission spectrographic analysis was subcontracted by Rocky Mountain Geochemical Corporation to Coors Spectro-chemical Laboratories in Golden, Colorado. Emission spectrographic sensitivities were equal to or better than those required by BFEC specifications for the NURE program.

The lower detection limit for uranium is 1 ppm. Values determined for some rocks, especially glassy volcanic rocks, are lower than those reported in the literature (Henry, 1978; Rytuba and others, 1979; Zielinski, 1978). These investigators suggested that uranium in glassy or partially glassy felsic volcanic rocks in the western United States is usually greater than 6 ppm. The uranium data for the Elko Quadrangle is useful for a relative comparison in defining favorable environments but may not represent the total-uranium content of many of the rock samples.

An aerial radiometric and magnetic survey was conducted by Geo-Life Incorporated (1979). A total of 3,036 line mi were flown, with east-west flight lines 2.75 mi apart and north-south flight lines 12 mi apart. These airborne data were not received until after the field work for this study was completed; consequently, these data could not be field checked. In addition, we flew 660 line mi of close-spaced airborne radiometric survey over areas containing potentially favorable environments.

Data from the Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) program were not received before completion of this study. Very few usable subsurface data were available within the Elko Quadrangle. Data from various types of logs were available for oil wells and some water wells throughout the quadrangle. Drillers' logs and geophysical logs of oil wells were available for examination at the Nevada Bureau of Mines and Geology, Reno, Nevada, and water-well data in the U.S. Geological Survey Water Resources Division District Office, Carson City, Nevada.

The geologic map (Pl. 16) was prepared under subcontact for the DOE by Willard Owens Associates Incorporated of Wheatridge, Colorado. The culture (Pl. 19) and drainage (Pl. 7) maps were supplied by BFEC.

GEOLOGIC SETTING

The Elko Quadrangle is an area of extremely complex and varied geology, thus it is convenient to break the quadrangle up into three individual portions for ease of discussion. This section will describe the geology of the three individual "geologic provinces": transitional to foreland basin sediments in the western part of the quadrangle ("western province"), the Ruby Mountains and East Humboldt igneous-metamorphic complex in the west-central part of the quadrangle ("Ruby Mountains - East Humboldt province"), and a continental shelf miogeosynclinal sedimentary section in the eastern part of the quadrangle ("eastern province"). Twenty-three major basins filled with ubiquitous Quaternary alluvium and Pleistocene playa lake sediments (Snyder and others, 1964) occur within the quadrangle. There are 28 established mining districts in the quadrangle. These districts are developed for a variety of base and precious metals, non-metallics, and energy resources.

Western Province

The western geologic province consists of mainly Paleozoic sedimentary rocks, rare Mesozoic sedimentary and volcanic rocks, Tertiary sediments and tuffaceous sediments, and lesser Tertiary volcanic and intrusive rocks covered by a substantial amount of Quaternary alluvial material. The stratigraphic and lithologic relations are shown in a generalized columnar section (Pl. 7).

The stratigraphy of the western province has been documented by numerous investigators, and the following discussion is largely a result of their work. The Paleozoic, Mesozoic, and Cenozoic geology of the Pinon Range, Huntington Valley, and Dixie Flats is well covered by Smith and Ketner (1975, 1976, 1977); the Diamond Mountains by Dott (1955); the Adobe Range by Ketner (1976) and Silitonga (1974); and the Miocene Humboldt Formation by Sharp (1939).

The Paleozoic stratigraphic section is well defined along the western edge of the quadrangle in the Pinon and Adobe Ranges. The Paleozoic section is represented by continuous sedimentation from Middle Ordovician through Late Permian. Lower Paleozoic miogeosynclinal, shallow-water sediments represent the first phase of sedimentation of predominately carbonate and subordinate clastic material. These formations exhibit characteristics of transitional facies rocks by their increased proportion of siliceous clastic material. Following the Late Devonian to Early Mississippian Antler orogeny and subsequent emplacement of the upper plate of the Roberts Mountain Thrust, a north-south linear uplift and paralleling downwarp (western portion of the Elko Quadrangle) formed along the leading edge of the upper plate (Poole, 1974). As a result, the environment of deposition changed profoundly with the influx of siliceous clastic material derived from the upper plate transition and western facies rocks into the eastward lying basin. Increase in grain size and amount of clastic sediments resulted as uplift continued, which culminated in the deposition of the Mississippian Diamond Peak Formation. Conditions changed during Pennsylvanian time, and calcareous and lesser siliceous detrital sediments predominated. Following a period of uplift in Late Pennsylvanian, there was a renewed influx of clastics from the east mixed with carbonate material. A regional uplift brought an end to marine deposition in Triassic time.

After Paleozoic marine deposition had ceased and a thick series of Jurassic volcanic rocks was deposited, folding and downwarping led to the development of basins. These basins became sites of deposition for lacustrine and fluvial nonvolcanic sediments during the early Tertiary (Eocene). The individual basins were filled and coalesced into a large lake basin of subdued topography. Tertiary volcanism began at 38.6 $\pm$ 1.2 M.Y.B.P. (Smith and Ketner, 1976). Volcanism included deposition of mafic to intermediate volcanic rocks, Indian Well Formation tuffs and tuffaceous sediments, and younger intermediate composition volcanics, all of which are Oligocene. During Miocene time, tuffs, limestone, and tuffaceous siltstone and sandstones of the Humboldt Formation were deposited; these were followed by a series of andesitic flow rocks. Volcanism continued into the Pleistocene. Intrusive activity during the Tertiary was relatively minor, commonly in the form of stocklike intrusions of silicic to intermediate composition. The Pliocene-Pleistocene sediments, tuffs and tuffaceous sediments, were last to be deposited.

Ruby Mountains - East Humboldt Province

The Ruby Mountains and East Humboldt Range are discussed together because of their geologic similarity and in a separate section because they divide the predominantly miogeosynclinal carbonate facies rocks to the east from the clastic-carbonate miogeosynclinal-transitional facies to the west. A generalized stratigraphic column is shown on Plate 7.

The East Humboldt Range has been studied in detail by Snelson (1957); although, small portions of the range were mapped by Howard and others (1979). Upper Precambrian to lower Paleozoic (Precambrian to Cambrian) rocks make up the bulk of the range and are thought to be the metamorphosed equivalents of nearby Paleozoic clastic and carbonate rocks. Along the southwest margin of the range, Middle Paleozoic to Lower Triassic unmetamorphosed rocks are in thrust contact (Secret Creek Thrust) with the above-described metamorphosed units. The metamorphic section consists of a fairly high-grade, regionally metamorphosed and internally thrusted succession that Snelson (1957) divides into two units. The lower unit (Angle Lake Unit) includes 3,000 feet of gneiss (granite, quartz diorite), schists, quartzites, calc-silicate rocks, and marbles. The upper unit (Snow Water Lake Unit) consists of 1,000 feet of polymetamorphic rocks that exhibit varying degrees of cataclasis and that include marble, calc-silicate rocks, quartzite, schists, and pegmatites. In late Cenozoic time, the entire East Humboldt Range was folded into a large north-trending, doubly plunging anticline.

Major geologic studies for the northern Ruby Mountains include: Howard (1966, 1971) and Smith and Howard (1977); for the southern Ruby Mountains, Sharp (1942) and Willden and Kistler (1967 and 1969); and for the entire range, Howard and others (1979).

In the northern Ruby Mountains, strata of Precambrian Z to Ordovician age are repeated by the Ogilvie Thrust Fault and are now recumbently folded by the Lamoille Creek Canyon Nappe (Smith and Howard, 1977). Ordovician-Devonian dolomite overlies Cambrian-Ordovician marble of the allochthon. Post thrust-fault Jurassic pegmatitic granite metamorphosed the lower Paleozoic strata to amphibolite-facies rock. Mesozoic(?) quartz monzonite and

granodiorite gneiss of the Lamoille Canyon Nappe were emplaced during metamorphism and folding. Pegmatite granite emplacement spanned the period of metamorphism and recumbent folding (Smith and Howard, 1977). A second phase of thrusting took place at the end of metamorphism and repeated the stratigraphic section and metamorphic gradient.

The central Ruby Mountains consist of predominately granite intrusive rocks and fewer Precambrian and lower Paleozoic rocks. Rocks of Middle Jurassic to early Oligocene age and of granite to granodiorite composition are mapped and described by Willden and Kistler (1969). Precambrian to Lower Cambrian rocks commonly occur as roof pendants and embayed remnants adjacent to granite intrusive rocks. The Precambrian rocks are surrounded by granitic rocks except to the north; here, they are in contact with Cambrian Prospect Mountain Quartzite. The intensity of metamorphism decreases southward. These Precambrian to Lower Paleozoic rocks have been folded into synclines and anticlines (normal, overturned, and plunging) of various orientations.

The Harrison Pass pluton is the major intrusive phase in the range and is composed of Oligocene (38 m.y.) biotite granodiorite to quartz monzonite. All the intrusive rocks are associated with abundant silicic dikes, veins, and beryl-bearing pegmatites.

The southern Ruby Mountains consist of a section of Upper Precambrian through Mississippian sedimentary rocks, locally intruded, metamorphosed, and embayed at the northern extension by the Harrison Pass pluton. Structurally, the section appears to be a simple eastward-dipping homocline tectonically disrupted by a series of high-angle normal faults to the south, the Lindsey Creek Thrust to the west, and granite intrusive activity to the north.

Eastern Province

The eastern geologic province consists of north-trending mountain ranges separated by the ubiquitous playa-lake valleys, Quaternary alluvial plains. For the most part, the rocks are of Cambrian or Tertiary age and are represented by Paleozoic miogeosynclinal sediments, Mesozoic sediments and intrusive rocks, and Tertiary through Quaternary volcanics and sediments. The entire eastern province can be broken into four convenient subdivisions having relatively similar geologic characteristics and are discussed accordingly. The generalized columnar section (Pl. 7) shows the geologic relations.

The Pequop Mountains, Spruce Mountains, and Wood Hills are located in the north-central portion of the quadrangle and are surrounded by playa-lake valleys. Paleozoic rocks range from Cambrian to Permian in age and are predominantly thick limestone sequences of the eastern carbonate assemblage with lesser transitional-assemblage rocks. Transitional-assemblage rocks were deposited as a carbonate-bearing detrital belt along the eastern margin of the Antler Orogenic Belt. The transitional rocks are in fault contact with eastern assemblage rocks (Hope, 1972; Thorman 1970). Metamorphosed equivalents of eastern-facies rocks make up the bulk of the Wood Hills (Thorman, 1970). High-angle and thrust faults disrupt the stratigraphic section in all of the ranges. In the Wood Hills a series of northeast-southwest-trending, overturned synclines and anticlines occur in addition to thrust and high-angle faults (Thorman, 1970). Tertiary quartz porphyry and

hornblende diorite crop out as dikes and stocks, as do minor dacitic tuffaceous volcanic rocks in the Spruce Mountains. Tertiary sediments and tuffaceous sediments and Quaternary alluvium are ubiquitous around the ranges.

The Butte Mountains, Delcer (Delker) Buttes, and Maverick Springs and Cherry Creek Ranges, in the central portion of the quadrangle, are predominantly Paleozoic sediments, lesser Tertiary volcanics and sediments, and intrusive rocks of unknown age. Small patches of Mesozoic sediments of Triassic age crop out in the southern Maverick Springs Range. Tertiary intrusive stocks of quartz monzonite to diorite are common throughout the Maverick Springs and Cherry Creek Ranges. Porphyritic quartz monzonite and monzonite stocks of unknown age make up the Delcer and West Buttes. Locally, the intrusive rocks form contact aureoles and metasomatic replacement rocks at locations where they intrude carbonate rocks. Tertiary volcanic rocks in the Maverick Springs Range and Butte Mountains consist of a thick sequence of pyroxene andesites, hornblende rhyodacites, and quartz latites with local intercalations of thin-bedded, air-fall, dacite tuffs and pumice breccias (Blake and Hose, 1966). Patchy outcrops of Tertiary tuffaceous and sedimentary rocks are also common. Structurally, the entire Paleozoic and Mesozoic sedimentary section is dissected by high-angle faults that generally trend north.

The third major area occupies the northeastern quarter of the quadrangle and includes the Pilot Range, Leppy Hills, and the Toano-Goshute Ferguson Mountains. Paleozoic rocks are from Cambrian through Permian in age, and all are eastern-facies foreland basin or shelf deposits. These sediments are well described by O'Neill (1968) for the Pilot Range, for the northern Toano Range by Pilger (1972), and for the Toano-Goshute Range by Hope and Coats (1976). Mesozoic sediments are relatively rare in this section and occur only in the Ferguson Mountains as local outcrops of Permian and Triassic clastic material. Cretaceous intrusive rocks of the northern Toano Range occur as two distinct granodiorite plutons (Pilger, 1972). Tertiary rocks are a minor fraction of the total volume of rock exposed in these areas; however, they form a substantial proportion of the northern Goshute Mountains and western Leppy Hills. Felsic to intermediate composition volcanic rocks in the form of flows, domes, and nonwelded ash-flow tuffs make up most of the Tertiary section. Compositionally, the volcanic rocks range from rhyolite to dacite. Tuffaceous sedimentary rocks locally occur throughout the Goshute-Toano Range. Structurally, the entire area is tectonically dissected by high-angle faults that generally trend north to northwest. Thrust faults are relatively rare.

The last area that will be discussed is in the southeastern portion of the quadrangle and includes the Dolly Varden Mountains, Antelope and Schell Creek Ranges, Kingsley Mountains, Currie Hills, and southern Goshute Mountains. Paleozoic rocks are almost all Pennsylvanian or Permian carbonates; although, lower Paleozoic carbonates crop out in the Kingsley Mountains (Buckely, 1967). Abundant Mesozoic clastic and carbonate facies crop out north and southeast of Currie (Nelson, 1956; Sirkin, 1970). Permian and Triassic limestones, correlative with the Moenkopi and Thaynes Formations of Utah, and Jurassic clastic rocks equivalent to the Nugget Formation of southern Nevada, crop out north of Currie. Granite intrusive rocks of Cretaceous to Tertiary age occur as stocks and include the Dolly Varden, White Horse, Ferber, and Kingsley intrusives (in order of decreasing size). All of these stocks typically have a composition of quartz monzonite. All stocks

mentioned are associated with metal-mining districts. Tertiary volcanic and sedimentary rocks cover the major portion of this section. Felsic to intermediate volcanic flows, ash flows, ash-flow tuffs, and localized domes constitute the largest volume of rock. Compositions are from rhyolites to dacites (lesser andesites) and exhibit a variety of textural types. Tertiary tuffaceous sediments and other sediments are also abundant. These units are predominantly nonwelded to welded ash-flow tuffs interbedded with water-laid, well-bedded, tuffaceous clastic and carbonate rocks. Structurally, both Paleozoic and Tertiary rocks are cut by numerous high-angle faults of various orientations.

ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

SUMMARY

In the Elko Quadrangle, four areas have environments favorable for the occurrence of uranium deposits (Pl. 1). One area (Area A) is favorable for initial-magmatic deposits (Class 510; Pilcher, 1978) and is located north of the south fork of the Humboldt River. The occurrence is contained in the tuffaceous portion of the Miocene Humboldt Formation.

One area is favorable for sandstone uranium deposits (Class 240; Austin and D'Andrea, 1978). Roll-type deposits occurring in intermontane basins (Subclass 241) crop out on the west side of Huntington Creek (Area B) in clastic carbonate sediments of the Miocene Humboldt Formation.

Contact metasomatic deposits (Class 340) and allogenic deposits (Class 360), as defined by Mathews (1978a), are found in Areas C and D, respectively. Both classes of deposits are associated with quartz monzonite intrusives of the Delcer Buttes and the enclosing Park City Limestone.

FAVORABLE AREA A - WHITE HILL

The White Hill No. 1 Claim (uranium occurrence 1) is located about 25 mi southeast of Elko (Pl. 2) and is classified as initial magmatic (Class 510). Minor development was done in the 1950's. Detailed geologic features are shown on Plate 9.

The White Hill No. 1 occurrence is within a tuffaceous section of the Miocene Humboldt Formation. The major rock types (Pl. 9) in the area of the occurrence include white to buff, locally tuffaceous, fine-grained limestones; gray to white, well-bedded volcanic ash tuffs; dark-gray, vitric and crystal tuffs; and thick-bedded gray-white ash with abundant interbedded dark-gray to black silicified lenses. The interbedded ash is finely laminated and has local development of sedimentary structures and concentrations of lapilli and pumice blocks. Silicified beds are commonly less than 3 ft thick and interbedded ash up to 10 ft thick. Other rock units include thin pebble conglomerates and tuffaceous sandstone beds. In general, the Humboldt Formation appears homoclinal, uncomplicated by faults, and of fluvial-lacustrine origin in the area of the occurrence.

Petrology

Petrographically, the tuffaceous rocks exhibit a commonly horizontal orientation of glass shards throughout most samples. All samples examined exhibit no evidence of welding such as flattening or stretching of glass shards, flow structures, etc.

Mineralogically, most unaltered samples consist of 96-98% glass in the form of shards and interstitial silica with sparse fragments and crystals of quartz, sanidine, and plagioclase. Much quartz and feldspar occurs as angular fragments possibly of detrital origin. Traces of biotite, opaque iron 44 oxides, sphene, and zircon also occur. Unaltered to slightly altered mineral relations are preserved in the dark-gray silicified beds within the gray tuff beds. The more abundant gray ash is a mass of glass shards and interstitial silica and is altered, to varying degrees, to secondary mineral products. Alteration products occur as semi-opaque clouded inclusions and globular aggregates developed within the glass. Gradational alteration is commonly observed when moving from dark-gray to gray-white friable beds. Diagenetic alteration is most developed in the friable gray-white ash tuffs. Alteration products appear to be feldspar and zeolites based on their mineralogy(?) and the common association of these authigenic minerals with altered tuffs as documented by other workers (Rytuba and others, 1979). These investigators indicate that potassium feldspar and zeolite family minerals such as clinoptilolite, erionite, etc., are common diagenetic alteration products of silicic tuffs. Well-defined zeolite crystals as described by Henry and Walton (1978) are not recognized in thin section, and the mineralogic nature of finely aggregated diagenetic material cannot be positively identified without other types of detailed analysis. Most glass shards exhibit evidence of devitrification in the form of thin, altered zones paralleling the outline of the shard. These zones are weakly birefringent, as described by Ross and Smith (1961) in slightly devitrified ash-flow tuffs, and are thought to be axiolitic growths of fine-grained aggregates of cristobalite and orthoclase.

Chemistry and Uranium Abundance

The ash-tuff members of the Humboldt Formation in the White Hill No. 1 Claim area have been chemically analyzed to help define processes involved in uranium concentration within specific rock units. As previously described, anomalous uranium concentrations occur only in the hard, dark-gray, glassy silicified tuffs; all non-silicified tuffs contain less than 5 ppm U_3O_8 (except where invaded by solution fronts). In contrast, interbedded silicified horizons may contain up to 270 ppm U_3O_8.

Whole-rock chemical analyses (App. B) indicate that the silicified ash is enriched in SiO_2, Al_2O_3, and TiO_2 and depleted in all other major oxides relative to the ash unit. Goodell and others (1978) have described the chemical alteration of rhyolitic rocks in the Sierra Pena Blanca deposits of Mexico; these deposits show enrichment in SiO_2, MgO, Fe_2O_3, and CaO in altered equivalents of tuffaceous rocks and relative depletion of K_2O, Na_2O, and Al_2O_3, in fresh samples of rhyolite tuffs. The Humboldt Formation rhyolite tuffs exhibit similar trends for Al_2O, Fe_2O_3, MgO, CaO, TiO_2, and MnO. Silica content is higher in silicified samples, as expected; although, Na_2O and K_2O are relatively enriched in the altered

sample, which is in direct contrast to the Pena Blanca tuffs. The relative increase of alkalis at White Hill may be due to formation of zeolites and potassium feldspar as described at the McDermitt Caldera by Rytuba and Glanzman (1979). These mineral reactions would use abundant Na_2O, K_2O, some CaO, and Al_2O_3 as observed at White Hill in the altered ash tuff. Trace-element data (App. B) indicate that both silicified and altered ash tuffs are relatively enriched in Cr, Cu, Fe, Se, Ti, V, Y, and Zr in association with anomalous uranium concentrations in these rocks. Boron appears relatively enriched in ash samples and lithium in silicified samples.

Gamma-ray spectrometric data (Table 1) indicate that most ash beds have a Th/U ratio of about 4.0 to 8.0 depending upon the degree of alteration; silicified beds average about 0.65; and, where iron-manganese oxide-rich solution fronts have moved through the gray altered ash, the average ratios are about 0.50. The silicified ash tuffs have ratios ranging from 0.13 to 4.48. All samples containing high anomalous uranium concentrations have ratios of 0.5 or less, which indicates uranium enrichment. The low Th/U ratios and high uranium contents of ash beds affected by solution-front movement indicate uranium enrichment. Most ash beds unaffected by secondary solution addition have normal Th/U ratios in the 2 to 6 range.

Chemical and spectrometric data indicate that one of two mechanisms could explain anomalous concentrations of uranium in tuffaceous rocks: 1) initial magmatic enrichment of uranium in the tuffs with subsequent silica deposition and leaching; and/or, 2) diagenetically derived silica anomalously enriched in uranium from alteration of tuffs.

If the ash tuffs were enriched in uranium magmatically before deposition, the tuff section had a high initial uranium content. Based on sample results, a substantial amount of uranium has been removed by some type of alteration-leaching mechanism. In the silicified beds, the initial uranium content is preserved by silicification. The uranium content of most silicified zones is 30 ppm uranium or less. Zones carrying high anomalous uranium contents (MEY 009, 270 ppm U_3O_8) commonly have been affected by later solution movement. The source of localization of silicification is not easily explained; however, silica derived from tuffaceous material by ground-water movement or downward-lateral migration and concentration along zones of permeability or fractured tuff sections is possible. Silicification is commonly observed at the top of the underlying limestone beds as silicified tufa tubes. Silicification transects all bedding and cross-bedding and is a postdepositional process that took place before substantial diagenesis, thus preserving the initial uranium content of the silicified tuffs.

The other mechanism for uranium enrichment is similar to uraniferous silica deposits of the Virgin Valley and Thomas Range of Nevada and Utah respectively (Henry, 1978). In these deposits, silica has been precipitated from ground water that has been in contact with and dissolved volcanic glass. Henry (1978) describes the solution of silica, subsequent alteration of tuffaceous volcanic rocks, and silica deposition at various localities. Much of the silica was deposited as opal and later converted to chalcedony under higher temperature conditions. Clay, zeolite, and feldspar alteration products of volcanic glass apparently correspond to those tentatively identified at White Hill. Henry (1978) also indicates that the uranium content of the silica deposited may change within an area. Ground-water

TABLE 1. RADIOMETRIC AND CHEMICAL RESULTS FROM THE WHITE HILL NO. 1 CLAIM URANIUM OCCURRENCE

Sample Associated Number	Total Gamma ray counts (cps)*	U_3O_8(Fl) (ppm)	Th/U	K_2O** (wt. %)	eU_3O_8 (ppm)	eTh** (ppm)	Significant Elem. (ppm)
MEY-001	850	26	0.29	1.29	167.8	48.3	-
MEY-002	1200	52	1.16	7.70	59.8	69.9	-
MEY-008	900	31	0.48	8.85	147.4	71.5	-
MEY-004	800	28	4.48	3.63	14.08	63.1	CU,Pb,Zr
MEY-008	750	1	4.38	2.62	8.48	37.18	Cu,Li,Pb,V
MEY-009	1600	270	-	-	-	-	Cu,Li,Pb,Zr
MEY-010	950	31	0.48	8.85	147.43	71.56	Fe,V
MEY-218	550	-1	-	-	-	-	Ni
MEY-219	210	2	-	-	-	-	
MEY-220	165	7	-	-	-	-	
MEY-225	155	4	-	-	-	-	
MEY-278	300	1	2.65	3.11	20.6	54.6	
MEY-323	900	6	0.48	3.86	97.48	46.76	Zr
MEY-324	1450	176	-	-	-	-	Zr

* The instrument used was a Mt. Sopris Model SC-131.
** The instrument used was a Geometrics GR-310.

movement (hot or cold) could mobilize uranium released during the alteration of volcanic glass shards and redeposit it in a siliceous phase from low-temperature diagenetic solutions. More detailed analyses are required to effectively evaluate the processes observed at White Hill; although, both mechanisms may have operated.

Origin of Silicified Zones

The genetic origin of the silicifed ash zones interbedded with the gray, friable ash is best explained by silicification of a pre-existing water-laid ash-tuff sequence. A very similar section of tuffs is exposed 8 mi to the southwest within the Humboldt Formation. Here Smith and Ketner (1977) believe the dark layers are silicified zones. These zones generally parallel or cross bedding at low angles with local pinching and swelling. Similar characteristics are exhibited at White Hill and appear to be of the same origin. The exact mechanism of silicification is unclear. Silicification rather than volcanic processes best explains the origin of these zones. The fine lamination, local cross bedding, silicification at low angles, paralleling bedding, the unwelded, non-deformed nature of the glass shards, and abundant detrital minerals (quartz, feldspar) indicate a sedimentary subaqueous deposition of the tuff section that later underwent local selective silicification. The silica source may have been diagenetic solution and redeposition of silica from the tuff section or externally derived silica-rich solutions migrating through the tuffs.

Conclusions

The Humboldt Formation at the White Hill No. 1 Claim meets the criteria for the initial-magmatic uranium deposits (Class 510). The tuffs appear to have had an initial magmatic enrichment of up to 30 ppm U_3O_8 prior to deposition. Later solutions moving through the tuff section diagenetically altered the ash, leached uranium, and deposited silica in irregular zones within the tuff. Still later, solutions, enriched in iron, manganese, and uranium, overprinted both silicification and ash-tuff zones. Both these mechanisms may be responsible, in part, for the local uranium depletion and enrichment within the tuff section. Thus, a tuff unit, initially magmatically enriched in uranium and acted upon by subsequent diagenetic and solution processess, appears to be the most logical explanation.

FAVORABLE AREA B - HUNTINGTON CREEK VALLEY

A sandstone uranium deposit (Class 241) occurs 18 mi due south of Elko along the west side of Huntington Creek Valley (Pl. 2). The occurrence (uranium occurrence 2) is small and is contained within the Miocene Humboldt Formation. Most of the outcrops are poorly exposed and are covered by Quaternary alluvial deposits and unconsolidated Humboldt Formation. The exact classification of this occurrence, according to the classification criteria, would probably be a peneconcordant deposit of Class 241. This part of the Humboldt Formation is somewhat analogous to the deposits of the Gas Hills of Wyoming; although, the characteristic abundance of alteration features and reductants is not observed. Sandstone and siltstone lithologies predominate

with lesser interbedded shales, limestones, and tuff beds in this part of the Humboldt Formation. The Humboldt Formation probably represents facies of the transition from fluvial to lacustrine sedimentation in this area and possibly is a shallow-water transition zone between the deeper portion of the lake and a near-shore environment.

The Huntington Creek occurrence lies within a section of interbedded sandstone, siltstone, shales, and limestones of the Humboldt Formation. The rock units are thinly bedded, poorly exposed, and commonly buff-gray or white in color. Almost all units examined have a tuffaceous fraction, and locally gray to white thin ash-tuff beds are common. Moving eastward, a facies change in the formation increases the tuffaceous and clastic (sand and silt) fraction. Westward, the formation is largely carbonate in composition and consists of limestone, silty-sandy limestone with thin interbedded ash tuff, sand, and chert beds. The limestone and clastic rocks of the two areas are tuffaceous to varying degrees and in some locales are highly tuffaceous. The Humboldt Formation is the only formation cropping out in the area of the occurrence and is a nearly flat-lying (0-10°) homoclinal sequence uncomplicated by faults and folds. To the north and west, Tertiary limestone and silicic to intermediate volcanics also crop out.

Petrology

A short discussion of the petrographic characteristics and provenance of the anomalous rocks will help define the geologic setting more clearly. The are three main lithologies mapped around the anomaly are shale, limestone, and sandstone, in order of increasing abundance (Pl. 8). Only the limestone and sandstone contain anomalous uranium. The sandstone unit contains local interlensed, thin pebble-conglomerate beds and locally abundant root casts.

The limestone is white to buff on a fresh surface, fine grained, and thinly bedded. Compositionally, it is made up of a fine-grained carbonate matrix with abundant angular to subangular, poorly to moderately sorted clastic material and volcanic glass. Clastic material includes quartz, potassium and plagioclase feldspar, biotite and muscovite micas, hornblende, clinopyroxene, iron oxides, sphene, and zircon. Some of the feldspar is slightly altered to sericitic and argillic products; but, overall, the feldspars and mafic minerals are relatively fresh. Sparry calcite fills voids, and rare oolites are observed. Volcanic glass shards are sharp and commonly unaltered in a micritic carbonate matrix. Some clasts are armored in a concentrically formed calcite shell. Most limestone is classified as silty to sandy limestone; although; local silty-tuffaceous limestone beds also occur.

In decreasing order of abundance, the sandstone is composed of predominantly quartz, potassium and plagioclase feldspar, muscovite, hornblende, clinopyroxene, iron oxides and abundant sphene, zircon, and other unidentified heavy minerals. The feldspar and mafic minerals are more altered than in the limestones. Clastic grains are from silt to sand size, angular to subrounded, and moderately well sorted; many of those clastic grains are the nucleus for oolitic overgrowths of fine-grained calcite by silica and carbonate material.

Provenance for the clastic material must have been relatively near and of granitic origin. The distance of transport was relatively short, which is reflected by the angular nature of all constituents. The minimal alteration of transported material indicates rapid uplift and erosion of the source rock. The rapid uplift of the Ruby Mountains in Miocene and later time (Sharp, 1942) means a nearby source for the clastic material observed in the samples. Volcanic material is abundant throughout the Humboldt Formation as thin to thick ash and vitric tuffs. A volcanic source area for this material is unidentified as yet.

Gamma-ray spectrometric readings and rock samples were taken of the anomalous rocks. These data indicate that both sandstone and limestone are uraniferous and commonly contain greater than 200 ppm U_3O_8. Gamma-ray spectrometric data indicate uranium contents greater than 50 ppm eU_3O_8, very low thorium contents, and Th/U ratios all less than 1.0 (0.4 to 0.8). These analytical data are summarized in Table 2. Trace-element analyses (App. B) indicate enrichment in Cu, Na, Mn, Sr, Ti, and V (with respect to non-uraniferous samples), in addition to U. Possibly, this reflects the granite clastic material in the sediments. Whole-rock analyses were not available for study.

Discussion

The sandstones exhibit little evidence of ground-water movement, solution fronts, or uraniferous mineralization in outcrop or in thin section. The anomalous uranium content may be partly attributed to detrital heavy minerals from a granitic source. In thin section, abundant sphene, zircon, and unidentified opaque minerals are found between the larger clastic grains (quartz, feldspar, etc.). Localized lenticular pebble-conglomerate lenses within the sandstone are anomalously radioactive, and gamma-ray spectrometric and chemical-uranium data indicate these beds contain the highest uranium contents. The pebble conglomerates also contain an abundance of detrital heavy minerals, which possibly represents a mini-conglomeratic placer deposit. The anomalously uraniferous granitic rocks of the Ruby Mountains (Harrison Pass pluton) may be contributing radioactive heavy minerals to the sediments. It is beyond our capabilities to determine if any of the opaque mineral grains are uranium bearing.

The tuffaceous fraction is locally highly altered to secondary clays and possibly zeolites, but most glass shards are relatively fresh. A portion of the uranium content may be attributed to glass diagenesis; but, with little evidence of solution movement through the sandstone, the migration of uranium released through diagenetic processes was probably negligible.

The limestone is highly uraniferous, locally more so than the underlying sandstone. Three rock samples of the tuffaceous limestone all contain greater than 240 ppm U_3O_8. Th/U ratios average about 0.1, and eU_3O_8 is commonly around 100 ppm. These highly anomalous amounts of uranium in a limestone are unusual unless, again, they are attributed to detrital heavy minerals and uraniferous glass shards.

In places, the mineralization appears to be concentrated along the contact between the sandstone and overlying limestone. This zone appears to

TABLE 2. RADIOMETRIC AND CHEMICAL RESULTS FROM THE HUNTINGTON CREEK URANIUM OCCURRENCE

Sample number	Total gamma ray counts (cps)*	U_3O_8(Fl) (ppm)	Th/U	K_2O** (wt. %)	eU_3O_8 (ppm)	eTh** (ppm)	Significant associated elem. (ppm)
MEY-141	1200	240	.10	92	9.7	1.6	-
MEY-142	1100	35	-	-	-	-	-
MEY-303	650	48	.13	39.3	5.27	0.71	V,Cu,Ti,Mn
MEY-304	1600	240	.04	248	11.6	0.06	Ti, Mn, V
MEY-321	1000	379	.07	102	7.28	1.45	Mn, Sr
MEY-322	1000	440	-	-	-	-	-

* The instrument used was a Mt. Sopris Model SC-131.
** The instrument used was a Scintrex, Model GAD-6.

have been slightly silicified. All anomalous uranium concentration is not confined to this zone, but concentration appears to be irregularly distributed throughout the sediments on both sides of the silicified zone. Uraniferous silica-rich solutions moving along this contact may be responsible for part of this localized concentration.

Conclusions

The Huntington Creek anomaly meets most criteria for sandstone class (241), but it lacks the conspicuous alteration features usually associated with deposits of this type. Uraniferous solutions moving through the rocks are not a likely source of mineralization because of the lack of alteration to the host rocks, relatively impermeable limestones, and because abundance of carbonate in both rock types would tend to keep uranium ions in solution. If uraniferous solutions did migrate through the rocks, or more likely along contacts, then reducing agents within the rocks are not conspicuous. No sulfide or phosphatic material, and very little organic debris, is observed in the rocks. Possibly a combination of detrital clastic material, uraniferous silica-rich solutions, and diagenetic alteration of glass shards is responsible for the uranium content. Detrital minerals are very abundant in the conglomerates and may be responsible for most of their uranium content; Although, uranium-bearing siliceous solutions may have played a more important mineralizing role along the sediment contacts between differing lithologies and may have dispersed outward from these contacts.

FAVORABLE AREA C - DELCER BUTTES

Contact metasomatic environments (Class 340) are common throughout the Elko Quadrangle: they result from emplacement of granite bodies into carbonate sequences. The result is contact metamorphism and subsequent reaction of a later stage aqueous metasomatizing solution with the host carbonates. Gamma-ray spectrometric and sample data indicate that many of the contact metasomatic environments have higher than normal concentrations of uranium. Preliminary data identify the Delcer Buttes as the only example of this type of environment considered favorable. The following discussion will be restricted to contact metasomatic zones and geologic setting of uranium occurrence 4.

Delcer - West Buttes Quartz Monzonite

The Delcer - West Buttes intrusive is composed primarily of quartz monzonite (granite to monzonite) in contact with Permian Park City Group and silty limestones and lesser quantities of contact metasomatic rocks. Intrusive rocks are predominantly hypidiomorphic-granular to porphyritic in texture and are of unknown age. Biotite and hornblende are the common mafic minerals in a typical quartz-feldspar matrix. Radiometric and chemical-uranium analytical data indicate that this intrusive is anomalous in uranium and averages about 6.4 ppm U_3O_8. The average uranium content of 6.4 ppm is above crustal averages (4.3 ppm) for rocks of similar composition listed by Taylor (1964) and Vinogradov (1962). The chemical analysis results in Appendix B (MEY 074) approximate those for a quartz monzonite of Nockolds

(1954). The differentiation index is 78.4, and the agpaitic coefficient is 0.66. Trace-element abundances for several quartz monzonite samples show enrichment of B, Cu, Mo, Pb, V, Y, and Zr, especially at locations where the samples are enriched in uranium. Geochemical studies of the Granite Mountains of Wyoming (Stuckless and others, 1977) indicate that these rocks contain anomalously high concentrations of uranium (average 10 ppm U_3O_8). The Granite Mountains are thought to be source rocks for Wyoming uranium deposits such as the Shirley Basin and Gas Hills. Preliminary sampling of the Delcer - West Buttes quartz monzonite indicates that it is relatively uraniferous when compared to other granitic bodies in the area and approaches the average for the Granite Mountains.

Contact Metasomatic Rocks

Contact metasomatic rocks developed along igneous-carbonate contacts consist of predominantly calc-silicate and sulfide minerals. The major mineral phases include andradite garnet, hedenbergitic pyroxene, calcite, limonite pseudomorphs after pyrite, and specular hematite. Secondary alteration and oxidation products are abundant and include massive limonite, copper carbonates and silicates (malachite, azurite, and chrysocolla), nontronite, and clay alteration products of primary silicate minerals. It appears that metasomatizing solutions were highly enriched in iron and lesser copper, and these metals were deposited as sulfides contemporaneously with, and following, calc-silicate mineral formation.

Subsequent oxidation has produced the suite of secondary minerals observed. No primary or secondary uranium minerals have been identified in hand specimen, although fine-grained disseminations could easily be missed in the highly oxidized and altered rock. The chemistry of the metasomatized rocks is typical of rocks of this origin. Enrichment of SiO_2, Al_2O_3, NaO_2, and MgO and depletion of CaO in the parent carbonate rock (MEY 069, App. B) reflects metasomatic reaction. Trace-element data (samples MEY 74, 155, 156; App. B) indicate enrichment of As, Be, Cu, Ni, Sc, and U; whereas, Ba, Pb, Sr, Ti, V, and Zr concentrations are lower than those average for non-uraniferous granitic rocks in the quadrangle. The more uraniferous calc-silicate rocks are not in direct contact (as seen on the surface) with quartz monzonite; instead, they are in contact with numerous latite to quartz latite dikes. The abundance of dikes and degree of contact metamorphism of host carbonate sediments suggest the main intrusive body is probably at shallow depth below these outcrops. Near the dikes the carbonate rocks are highly silicified and calc-silicate hornfels are developed in siliceous carbonate rocks. Along the contact with the main intrusive phase, the carbonate rocks are bleached and silicified in addition to contact metamorphic and metasomatic features development. Varying amounts of shearing and local cataclasis are developed along the contact zones, in response to igneous emplacement.

Conclusions

Most contact zones examined are of limited surface exposure and frequently covered by alluvium or granitic float from the stock. Because it is impossible to estimate the overall dimensions of the contact zones, the amount of material contained in these zones is also impossible to estimate.

The contact zones are relatively thin and lenticular. The widest zone encountered is 10 ft, though most average 5-7 ft, wide. The longest zone (exposed at the surface) is 65 ft long; although, both ends are covered, and vertical dimensions are unknown. Where a substantial thickness of carbonate rock is in contact with intrusive rock, vertical entensions could be large. Surface radiometric readings along these zones were surprisingly low, possibly due to uranium mineralization being out of equilibrium in favor of chemical uranium, so that their significance was not fully appreciated before the results of the chemical analyses were obtained. As this was very late in the project, there was insufficient time for further delineation of outcrop extensions and more detailed geologic work.

The Delcer - West Buttes intrusive cannot be considered an orthomagmatic uranium deposit; it does exhibit many characteristics of uraniferous granitic rocks (Mathews, 1978a), such as intrusive geometry, petrology, textures, alteration, relatively high SiO_2 K_2O, and NaO_2, and tectonic setting. The mineralogical makeup is somewhat similar except for the lack of sodic pyroxenes and amphiboles, fluorite, and uranium accessory minerals. Granitic rocks are spatially associated with anomalous concentrations of uranium in host rocks. These data indicate the stock is not orthomagmatically enriched in uranium but does display some compositional and geologic parameters characteristic of uraniferous plutons. The stock is considered a center of anomalous uranium concentrations.

FAVORABLE AREA D - WEST BUTTES

Allogenic deposits (Class 360; Mathews, 1978a) abundantly occur along the northwest side of West Buttes (uranium occurrences 3 and 5), exhibit geologic relationships similar to those described under the contact-metasomatic section, and meet the criteria of Mathews (1978a). The contact metasomatic rocks with associated allogenic mineralization are developed along the contact zone or within and along shear zones immediately adjacent to the contact zone (within 100 ft). Two separate areas are included in this section and will be discussed below.

West Butte Occurrence

The rocks described at occurrence 3 (contact metasomatic) are very similar to those at the West Butte occurrence. A well-developed zoned sequence consists of quartz monzonite, limonite-gossan zone, contact metasomatic calc-silicate zone, bleached and calc-silicated limestone, and a limestone zone. The contact metasomatic rock is composed of andraditic garnet, pyroxene, epidote, calcite, specular hematite, and ubiquitous iron oxides and copper silicates. Rare, unoxidized chalcopyrite and pyrite grains are enclosed within massive calc-silicate minerals. Limonitic gossan and associated jasperoid are developed within and adjacent to contact metasomatic rocks along the contact. In some of the pits and trenches developed on these zones, shearing, localized gouge zones, and lightly altered and argillized zones are evident. Anomalously radioactive and uraniferous rocks are always along the limonitically altered and sheared contact metasomatic and gossan zones.

Two rock samples, MEY 163 and MEY 165, were collected for analysis; results were 32 and 510 ppm U_3O_8, respectively. (Other sample results are summarized in Table 3). Many other gossan outcrops could be sampled, but none are as radioactive as the MEY 165 sample area.

Similar geologic situations are developed along the southwest margin of the stock about 1 mi to the south and are considered part of the same occurrence. Well-developed contact metasomatic rocks occur along a nearly east-west fault zone, along which five shafts were sunk. Garnet, idocrase, epidote, and hedenbergitic clinopyroxene are the abundant calc-silicate minerals with lesser quantities of calcite, magnetite, nontronite, and limonite. Iron and manganese oxides, copper silicates, and minor carbonate minerals make up a large portion of the contact zone. The enclosing limestones of the Park City Group are silicated and locally bleached in addition to exhibiting thermal effects. All radioactive anomalies are located along shear-contact zones, none are along the stock-sedimentary rock contact that exhibits only thermal metamorphic effects. The radioactively anomalous zone is about 580 ft long; although, most of the zone is unexposed at the surface due to lack of exploratory work. Further to the east, numerous small occurrences of slightly metasomatized rocks crop out but are mostly unexplored. The total length of the zone may be up to 1000 ft including the easternmost exposures. In most places, the zone is narrow and averages less than 5 ft in thickness. Only one sample (MEY 072) of the zone was collected; analysis results included 84 ppm U_3O_8.

Tumbee Occurrence

The Tumbee occurrence (uranium occurrence 3) is similar geologically to, and occurs 1 mi south of, the above occurrence on the west side of the intrusive. It is also along shear zones in the carbonate host rock near the intrusive contact. Numerous trenches, pits, and an inclined shaft expose the major outcrops. Most pits and the inclined shaft are along shears; although, a large fine-grained quartz monzonite dike has altered zones along its contact with the carbonate host. Varying amounts of calc-silicate contact metasomatic minerals are developed from place to place with ubiquitous silicified, bleached, and locally leached and oxidized carbonate host rocks. It appears that the degree of fracturing and shearing may be important to the location of mineralization. Zones of limonitic rocks are commonly 2-5 ft wide and up to 100 ft long. Again, exposures are poor. Radiometrically, the altered rocks are low (75-200 cps). One sample collected (MEY 075) on the most anomalously radioactive zone (500 cps) had 281 ppm U_3O_8.

Conclusions

Whole-rock and trace-element geochemistry results are not available for rocks hosting allogenic mineralization, and only a few samples were collected for uranium determination. The degree of uranium enrichment is relatively high in the allogenic rocks but is restricted in size. Size restrictions appear to severely limit the potential for minable volumes of ore-grade material based on these preliminary data.

TABLE 3. RADIOMETRIC AND CHEMICAL RESULTS FROM CONTACT METASOMATIC AND ALLOGENIC URANIUM ENVIRONMENTS OF THE DELCER - WEST BUTTES AREA

Occurrence No. (ppm)	Sample number	Total Gamma (cps)*	U_3O_8(Fl) (ppm)	Significant associated elements
3	MEY-075	540	281	Ni, Cu
	MEY-067	160	3	-
4**	MEY-068	275	12	-
	MEY-069	220	30	-
	MEY-071	160	1	-
	MEY-072	350	84	-
5	MEY-163	240	32	-
	MEY-164	200	9	-
	MEY-165	800	510	-

* Mt.Sopris, SC-135
** Occurrence No. 4 is contact metasomatic, No. 3 and 5 are allogenic.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

SUMMARY

Ten environments within the Elko Quadrangle are considered unfavorable for uranium deposits as defined by Mickle and Mathews (eds., 1978). These environments exhibit a variety of geologic settings and include:

Mesozoic-Tertiary plutonic rocks

Tertiary volcanic rocks

Contact metasomatic rocks

Anatectic rocks

Pegmatitic rocks

Carbonaceous shales

Marine black shales

Limestones

Sandstones

Phosphorites

MESOZOIC-TERTIARY PLUTONIC ROCKS

Plutonic rocks are common throughout the quadrangle in the form of stocks and plutons; they vary in composition from granite to diorite and range in age from Jurassic to Tertiary (Oligocene). Many of the igneous intrusive rocks are associated with various types of metallic ore deposits. There are eight possible genetic classifications or uranium occurrences related to igneous rocks. In the Elko Quadrangle, contact metasomatic and allogenic types are considered favorable; orthomagmatic, pegmatitic, contact metasomatic, magmatic-hydrothermal, and anatectic are considered unfavorable. Autometasomatic and authigenic environments were looked for but not identified. Appendix D is a listing of all major igneous intrusive rocks in the quadrangle with their compositions, ages, and locations. Appendix B is a table of whole-rock chemistry analyses for the intrusive rocks.

Throughout the quadrangle, numerous examples of magmatic-hydrothermal vein-type deposits exist; although, none are uraniferous. All examples investigated appear to be base-metal, base-metal--silver, or tungsten-bearing quartz veins. The major areas examined include Ferguson Spring district (T. 30 N., R. 69 E.), Mud Spring district (T. 28 N., R. 60 E.), Spruce Mountain district (T. 31 N., R. 69 E.), Proctor district (T. 35 N., R. 68 E.), and White Horse district (T. 28 N., R. 68 E.). Most of the areas are quartz-calcite + barite veins developed along fault or shear zones. The veins contain lead-zinc-silver + gold in primary sulfides or oxidized minerals in limonitic gossan matrix.

All vein systems examined are radiometrically low (less than 200 cps). Most of the vein systems exhibit characteristics similar to those listed in the recognition criteria, such as association with base metal sulfides ± silver and gold; occurrences of anomalous Mo, Au, Ag, Ca, F, and As; silicification and argillic alteration; and existence as multiple-vein systems frequently associated with leucocratic rocks of granite to quartz monzonite composition.

Highly anomalous radioactivity is lacking. Rock samples collected have from 1-55 ppm U_3O_8; but most samples have less than 5 ppm uranium. The one highly anomalous sample (MEY 254) was collected from a replacement base-metal silver deposit in the Kingsley district. Many of the unoxidized vein systems are not accessable; most samples came from dumps or from highly oxidized outcrops.

Orthomagmatic

Igneous intrusive rocks throughout the quadrangle were examined for orthomagmatic uranium deposits by ground and airborne radiometric surveys and collection of numerous rock samples. The following discussion will deal with important factors for the delineation of orthomagmatic plutonic rocks. Intrusive rocks lying within the Elko Quadrangle exhibit a variety of compositions, textures, and size. Most are stock-sized bodies and quartz monzonite to granodiorite composition. Ages range from Jurassic to Tertiary (160 to 36 M.Y.B.P.); although, many are of unknown age.

Southeast Section

In the southeast quarter of the quadrangle, four major stocks crop out, Melrose, White Horse, Kingsley, and Ferber. These stocks are medium-grained porphyritic quartz monzonite. Compositional variations and gradations exist but make up less than 20% of the stocks. Mineralogically, the rocks contain 12-30% quartz, 15-40% potassium feldspar, 25-40% twinned and oscillatory-zoned plagioclase, 10-15% perthite, 2-15% biotite, and 1-15% hornblende. Chlorite and epidote alteration products and accessory sphene, apatite, zircon, allanite, and magnetite also occur. Pyroxene may be locally abundant. Alteration is slight to moderate and includes sericitization, argillization, chloritization, and epidotization. Contacts with country rocks are commonly sharp. Local assimilation and xenolithic inclusions are common as are abundant aplite, pegmatite, and lamprophyre dikes. Contact metamorphic and metasomatic effects are common. The Melrose, Kingsley, and Ferber stocks contain anomalous concentrations of uranium (App. D). The Melrose stock is the most anomalous igneous body in the quadrangle and averages 8.77 ppm U_3O_8 for 11 samples (App. D). This value, although relatively high, does not approach that of orthomagmatic occurrences such as the Bokan Mountain Granite (20-200 ppm).

Northeast Section

The Toano Spring and Silver Zone Pass plutons crop out in the Toano Range in the northeast quarter of the quadrangle and are described by Pilger (1972).

Both intrusives approximate granodiorite in composition; although, variations do exist. The Toano Spring intrusive is coarser grained and exhibits a distinct foliation concordant with the country rock. The Toano Spring Pluton has many pegmatitic dikes associated with it, but the Silver Zone Pass intrusive is composed of only one major phase. The Silver Zone Pass pluton is an equigranular granodiorite with up to 25% mafic minerals (13% biotite and 12% hornblende) and up to 1% accessory sphene, zircon, and apatite. Saussuritization of plagioclase, chloritization of mafics, and alteration to sericitic and carbonatitic products are common. Aplite dikes of silicic to intermediate compositions intrude the pluton. The Toano Spring pluton is petrologically and mineralogically similar to the Silver Zone Pass pluton. Mafic minerals are less abundant, and most minerals show evidence of cataclasis. Aplitic and pegmatitic dikes are abundant.

Rock samples range from 1 to 2 ppm U_3O_8. Sediment and water samples indicate an insignificant amount of uranium movement from the intrusive rocks.

Ruby Mountains

Plutonic rocks within the Ruby Mountains have been mapped by Willden and Kistler (1969) who define two major intrusive phases, the Harrison Pass pluton (38 m.y.) and the pegmatitic granite (160 m.y.), with smaller bodies of two-mica granite (82 m.y.), and sheared quartz monzonite. Aplite and pegmatite dikes and quartz veins and veinlets cut all intrusive phases. Xenolithic inclusions are common and, locally, at the contact, hybrid rocks occur. The pegmatitic granite has abundant mylonitic phases along its western margins.

The Harrison Pass pluton is composed predominantly of porphyritic quartz monzonite and biotite granodiorite characterized by large microcline phenocrysts (Willden and Kistler, 1969). The groundmass is predominantly quartz and potassium feldspar with quantities of plagioclase (An_{10-35}), hornblende, pyroxene, and abundant biotite. Varying degrees of sericitic and argillic alterations are observed. Minor accessory minerals are common and include sphene, zircon, and magnetite. Nineteen samples of the Harrison Pass pluton averaged 4.0 ppm U_3O_8. This average is not exceptionally high, but is the highest for a large intrusive mass in the Elko Quadrangle.

Delcer - West Buttes

The Delcer - West Buttes are of quartz monzonite to monzonite composition. The rocks have a hypidiomorphic-granular to porphyritic texture and, along the borders, a well-defined equigranular chill facies. Porphyritic quartz monzonite makes up the bulk of the stock. The quartz monzonite (unknown age) has intruded and contact metamorphosed (locally metasomatized) carbonate and silty-carbonate rocks.

Mineralogically, the intrusives consist of biotite, hornblende, and rare pyroxene in a predominately quartz-orthoclase matrix with lesser plagioclase (An_{30}, oscillatory zoned). Abundant sericitic, chloritic, and argillic alteration products occur along with abundant sphene, zircon, and opaque

minerals (magnetite, illmenite, hematite?). Eight samples average 6.4 ppm U_3O_8 and are considered somewhat anomalous when compared to other igneous samples.

Conclusions

None of the intrusive bodies examined are highly anomalous in uranium as would be expected in orthomagmatic granite rocks such as the Bokan Mountain Granite (20-200 ppm U_3O_8). None of the intrusive bodies average greater than 10 ppm U_3O_8; although, individual samples may contain up to 24 ppm. The intrusive bodies examined are not orthomagmatically enriched in uranium, but the relatively anomalous bodies could act as uranium source rocks.

Most intrusives do not fit the criteria for orthomagmatic uranium occurrences, but as uranium content increases so does the degree of correlation with the criteria. In the Elko Quadrangle, uranium-enriched granitic rocks contain anomalous amounts of specific trace elements, such as As, B, Co, Ni, V, Y, and Zr, when compared to non-uraniferous granitic rocks. Major oxides exhibit no distinct anomalies relative to anomalous uranium enrichment. All anomalous igneous bodies are in the quartz monzonite-granite range. The differentiation indices all fall in the 75-80 range, and peralkalinity is around 0.60 for uraniferous rocks. Chemical data indicate the rocks are of calc-alkaline affinity. The major difference between orthomagmatically enriched plutons and the Elko igneous rocks is that the Elko rocks are low in NaO_2 and K_2O and thus lack sodic pyroxene and/or amphiboles, have a different degree of differentiation, and have a lower agpaitic coefficient. Most other characteristics are similar.

Many of the intrusives are above the world averages for granodiorites and granites of 3.5 ppm U_3O_8 (Vinogradov, 1962) and 4.8 ppm U (Taylor, 1964), respectively. Granitic quartz monzonite rocks of the western United States average about 4.3 ppm U_3O_8; these include the Sierra Nevada batholith at 4.3 ppm; the Idaho batholith at 4.4 ppm; and the Boulder batholith at 4.0 ppm (Larson and Gottfried, 1969). It is apparent from Appendix D that the Harrison Pass pluton is the only large granitic body at about average uranium content. The Delcer-Buttes, Melrose, and Ferber stocks have above-average and all other plutons sampled have below-average content.

Sample, chemical, petrographic, and world uranium average data indicate that none of the igneous bodies are orthomagmatically enriched in uranium. There is a possibility that some of the bodies may act as uranium source rocks because of their large size. Many anomalous water, soil, and stream-sediment samples around the Harrison Pass pluton indicate uraniferous detritus is being transported from the pluton, and some uranium is getting into the ground water. Anomalous soil and sediment samples around the Delcer and Melrose stocks indicate movement and concentration of uranium. Lack of springs makes it impossible to know how much uranium is getting into the ground water. All other igneous bodies are considered too small or have uranium contents too low to be of interest as uranium source rocks.

TERTIARY VOLCANIC ROCKS

Volcanic rocks, ranging in composition from rhyolite to basalt and in age from Jurassic to Miocene, occur abundantly throughout the Elko Quadrangle. Volcanic rocks are especially concentrated along the western, eastern, and southeastern margins of the quadrangle. Textures range from non-welded to welded ash-fall and ash-flow tuffs and flow rocks of varying mineralogical and lithological compositions. Many of the units consist of volcanic and interbedded lacustrine and fluviatile sediments. Portions of the Miocene Humboldt Formation are considered favorable for uranium deposits. Most of the Humboldt Formation is considered unfavorable for any type of volcanic uranium deposits. Unfavorable areas include the western margin of the quadrangle (Adobe Range, Elko Hills, Dixie and Huntington Valleys, southern Pinon Range - Diamond Hills area), the eastern margin (Silver Zone Pass, Leppy Hills, and northern Goshute Range), and the southeast section of the quadrangle (Dolly Varden Mountains, Currie Hills, Butte Mountains, Antelope - Schell Creek Ranges, and the southern Goshute Mountains.

All the above areas have been intensively radiometrically surveyed and sampled. The results of these surveys indicate that some of the volcanics may act as favorable uranium source rocks; however, primary deposits such as initial magmatic, pneumatogenic, hydroauthigenic, and hydroallogenic types are not considered to exist within the quadrangle (other than within the Humboldt Formation). In the following section, short summaries of the most interesting areas are presented with relevant sample and petrologic data.

Western Section

Along the western margin of the quadrangle, two major volcanic units occur, the Indian Well Formation and the Humboldt Formation. In addition, numerous other volcanic units of varying compositions exist throughout the area.

The Indian Well Formation of Smith and Ketner (1977) covers a large part of the western portion of the quadrangle and is made up of four members: the basal tuffaceous sediment, tuff, and ash-flow tuff unit; an ash-flow tuff; tuffaceous sedimentary rocks; and interlayered ash-flow tuff and tuffaceous sedimentary rocks. The Indian Well Formation rests unconformably upon older rocks. Compositionally, the ash-flow tuff is most nearly a quartz latite and ranges from rhyolite to dacite. Throughout the entire thickness of the formation, about 67% is composed of tuff and 33% of sediments, tuffaceous-clastic sediments, and non-welded ash. Radiometrically, the most interesting portion of the formation is the ash-flow tuff (unit 2). Unit 2 consists predominantly of ash-flow tuffs of dark-gray to purple to black color, slightly to densely welded vitrophyres, and have ash, crystal, crystal-lithic, and volcanic breccia textures. Quartz, potassium feldspar, plagioclase, and biotite phenocrysts are common within a glass-shard to welded-glass matrix.

Numerous samples were collected from the various tuff units of the formation. The average uranium content of for 31 samples was 2.2 ppm U_3O_8. The samples ranged from 1 to 24 ppm U_3O_8, which indicates that this formation is unfavorable for uranium deposits.

The Miocene Humboldt Formation is a mixture of fluviatile and lacustrine sediments, tuffaceous sediments, and tuffs (Smith and Ketner, 1976). Tuffs and tuffaceous sediments make up a small proportion of the section, usually less than 25% in measured sections. The tuffs are gray to white, thin bedded, locally silicified and friable, and contain phenocrysts of sanidine, plagioclase, quartz, and biotite and traces of magnetite, zircon, and pyroxene in a glass-shard matrix. Tuffaceous sediments consisting of silts, sands, conglomerates, and limestones occur throughout the section. Numerous radiometric traverses were made across major portions of the formation and many samples of all major rock types have been collected. Some tuffaceous rocks contain up to 270 ppm U_3O_8. Many of the ash beds appear somewhat altered to secondary minerals. With alteration and ground-water movement, initial uranium content may have been removed. All samples of silicified ash that were sampled contained relatively high values (up to 270 ppm U_3O_8) of uranium.

In the southwest corner of the quadrangle, a sequence of Oligocene flows with interlayered tuffs has a combined thickness of 1,000 ft. The volcanics range in composition from andesite to rare rhyolite are commonly fall within the andesite - quartz latite range (Smith and Ketner, 1976). Plagioclase, biotite, and pyroxene are abundant phenocrysts in a gray-glass groundmass. Radiometrically, these rocks are low, and all samples collected average less than 2.9 ppm U_3O_8.

Northeast of Elko, in the Elko Hills, rhyolitic flows and dacite hypabyssal rocks are in contact with Paleozoic clastic sediments. The rhyolite flow rocks consist of light-pink, fine-grained, crystalline groundmass with quartz and potassium feldspar phenocrysts. Most outcrops are slightly altered to secondary clay materials. The hypabyssal rocks are probably domelike intrusives. Phenocrysts include quartz, potassium feldspar, plagioclase, biotite, and hornblende prisms. Radiometrically, all rocks are low. Analyzed samples of the flow rocks range from 2 to 4 ppm U_3O_8, and the hypabyssal rocks average 1 ppm U_3O_8.

Eastern Section

A series of rhyolitic to dacitic volcanic rocks crop out in the northern Toano and Goshute Ranges and in the Leppy Hills along the eastern margin of the quadrangle. Many of the volcanic sequences examined are radiometrically anomalous and may be a uranium source upon devitrification.

In the northern Toano Range, a series of Tertiary (Miocene?) volcanic rocks crops out in the form of flows and tuffs (Hope and Coats, 1976). Rhyolitic in compostion, these volcanics exhibit varying textures such as porphyritic, crystal tuffs, and crystal vitrophyres. Phenocrysts of sanidine, albite, and quartz with local biotite occur in a light to dark gray glassy groundmass that has undergone varying degrees of welding and is slightly to moderately altered. Vesicles are common in flow rocks and are commonly lined with chalcedonic silica. Concentrations of secondary silica are common within the vitrophyres and overlying welded tuffs. All quartz phenocrysts are smoky (some very dark) as a result of radiation damage. Thickness of these units is unknown because of poorly exposed sections, but the vitrophyric tuff ranges from 50 to 75 ft thick. Gamma-ray spectrometric data indicate these rocks

contain up to 50 ppm eU_3O_8, and Th/U ratios are all greater than unity and range from 4 to 6. Radiometrically, the rhyolite porphyry has from 400 to 700 cps, and the welded tuffs from 600 to 1000 cps. Chemical-uranium content ranges from 2 to 12 ppm U_3O_8, but the highly radioactive vitrophyre contains only 3 ppm U_3O_8. Ground-water leaching and movement of uranium appear minor; a downdip well-water sample near the major outcrops contains only 8.2 ppb U_3O_8.

A sequence of Tertiary (Miocene?) silicic to intermediate volcanics covers a relatively large area on the east side of the northern Goshute Range. Compositions range from rhyolite to dacite, and the rocks crop out in the form of domes, tuffs, pyroclastics, and tuffaceous sediments. The radioactive rocks are rhyolite porphyry domes; mineralogically, they consist of quartz (smoky) and sanidine phenocrysts in a gray-white glassy groundmass. Quartz latite porphyry is volumetrically the most abundant rock in the area and forms steep, clifflike, reddish-brown outcrops. Large phenocrysts of potassium feldspar with lesser quartz and plagioclase occur in an aphanitic reddish groundmass. Rhyolite crystal tuffs, with various degrees of welding, commonly have secondary chalcedonic silica vug fillings. Water-laid, crystal-lithic, ash tuffs are locally common and lap up on the previously described volcanic units. Most rock units are moderately radioactive and contain relatively high eU_3O_8 values (up to 13 ppm in rhyolite porphyries); Th/U ratios are all greater than unity. Chemical uranium determinations of samples collected for analysis have a high of only 5 ppm U_3O_8 (rhyolite porphyry). Water samples in the area run 4.5-6.0 ppb U_3O_8. Chemical uranium data indicate that the rock units are not particularly anomalous in their uranium content, and water samples indicate very little ground-water leaching and movement of uranium.

The Leppy Hills contain a series of Miocene rhyolite to quartz latite porphyry flows. Most flow rocks have a gray-white to dark reddish groundmass with abundant quartz, sanidine, and plagioclase phenocrysts. Portions of the Miocene Jarbidge Rhyolite flows have been mapped by Hope and Coats (1976) in the Leppy Hills. The Jarbidge Rhyolite is light gray with abundant phenocrysts like other rhyolites in the area. Most outcrops are somewhat altered. Chemical uranium ranges from 1 to 4 ppm, with the Jarbidge Rhyolite containing the most uranium.

Southeastern Section

Abundant Oligocene(?) volcanic rocks of silicic to intermediate composition occur along the southeastern and southern margins of the quadrangle, including the southern Goshute Mountains, Antelope - Schell Creek Ranges, Butte Mountains, Currie Hills, and Dolly Varden Mountains.

Volcanic rocks range from quartz latite to pyroxene andesite; these occur as flows, air-fall tuffs, breccias, and thin-bedded vitrophyric tuffs; and they form thick red-brown masses of marked relief. These rocks have been studied in detail by Young (1960) and by Blake and Hose (1968) in northern White Pine County. The rocks have a light-gray groundmass with abundant plagioclase, biotite, hornblende, and pyroxene phenocrysts. Radiometrically, all units are low except for the Currie Hills; here, andesitic basaltic rocks are relatively anomalous (150-275 cps). Sample results show from 1 to 16 ppm

U_3O_8 and average 3.0 ppm U_3O_8 for 17 samples. These characteristics are similar for all areas except Dolly Varden and north of Currie.

The volcanics of the Dolly Varden Mountains and those north of Currie are of silicic to intermediate compostition, ranging from rhyolite to andesite. In the Dolly Varden Mountains, up to 2700 ft of volcanic rock is exposed, including flows and tuffs of Oligocene(?) age (Snow, 1963). The principal rock units include andesite, quartz latite, and rhyolite in the form of vitric tuffs, block and ash flow, vitrophyres, volcanic breccias, and ignimbrites. Textures include vitric-crystal, lapilli, vitrophyric, blocky, ash, and mixtures of these in various colors and varying degrees of welding; phenocrysts of quartz, biotite, potassium feldspar, plagioclase, hornblende, and pyroxene are locally abundant. The quartz latite unit of the Dolly Varden Mountains is a welded pyroclastic rock whose lithologies vary from crystal-lithic to felsite tuff of orange to brown in color. Phenocrysts of feldspar, biotite, and lesser quartz are most abundant. Rhyolite flows and tuffs commonly form reddish-brown outcrops in the Dolly Varden Mountains. The flows are light pink in color and are composed of thinly banded, welded, crystal-vitric, pumaceous, and vesicular tuffs (Snow, 1963). Phenocrysts include sanidine, plagioclase, and quartz and hematitically stained groundmass. Differentially welded ignimbrites composed of pyroclastic material and of quartz latitic composition are common throughout the Dolly Varden Mountains. The average thickness of the ignimbrite is 1000 feet, and it exhibits various degrees of welding.

The Currie volcanics (silicic volcanics north of Currie) are predominantly of rhyolite to quartz latite composition. All rock units are tuffs and include lapilli, crystal-lithic, and varying mixtures. These tuffs are welded to varying degrees, some are flow-banded, and some contain locally abundant phenocrysts of quartz, potassium feldspar, and biotite.

Numerous rock, soil, and water samples have been collected in the Dolly Varden and Currie areas in an attempt to define possible host and/or source rocks. Uranium contents of rock samples are from below detection to 16 ppm and average about 3 ppm U_3O_8 for 34 rock samples. Sediment samples around the Dolly Varden Mountains are somewhat anomalous (up to 7 ppm U_3O_8) but too few samples were collected to establish any meaningful conclusions.

Conclusions

All volcanic rocks looked at are relatively low in their uranium contents, the highest average is 3.0 ppm U_3O_8. Although many criteria for initial magmatic deposits are met, none of the areas meet all the criteria or have sufficiently high uranium content to be considered favorable for initail magmatic or any of the other volcanic-type deposits.

When comparing whole-rock chemical and trace-element data, very few direct correlations can be made with uranium content. Relative trace-element abundances indicate that rocks enriched in uranium are usually enriched in Li, Y, and Zr. All other trace-element abundances exhibit no marked overall changes, although within some volcanic rock groups Ni, Ti, and B are enriched in rocks containing anomalous uranium contents. Trace-element analyses are

not available for all samples collected; consequently, these results could change if more data were available.

Volcanics having relatively anomalous uranium contents fall into the rhyolite - quartz latite range of composition as indicated by whole-rock chemical data. The differentiation index is greater than 85.0 and the agpaitic coefficient is greater than 0.60 for all anomalous groups. The water-laid ash tuffs of the Humboldt Formation also fall within these ranges.

Gamma-ray spectrometer data indicate that Th/U ratios fall within the 2.0 6.0 general range of normal volcanic rock ratios (Pilcher, 1978). Stream-sediment, soil, and water sample data exhibit some anomalies around volcanic terrains but, for the most part, are relatively low. Anomalies are the highest around the Dolly Varden Mountains.

The amount of uranium that was leached from the volcanics and moved by ground water appears negligible from water sample data. When dealing with only surface data, it is impossible to know what is happening in basin environments. Weathering and erosion may have deposited much material in basin environments. Ground-water movement and leaching, diagenetic alteration, and other similar processes may have mobilized uranium from volcanic rock and/or detritus and deposited it in favorable portions of the basin environment.

CONTACT METASOMATIC ROCKS

Contact metasomatic environments (Class 340) abundantly occur in the Elko Quadrangle around Mesozoic-Cenozoic granitic stocks and plutons in contact with carbonate sediments. Spatial distribution and temporal relations of intrusives are shown on the geologic map (Pl. 6). Many of the larger contact metasomatic environments are in established mining districts. Most contact deposits show little uranium concentration.

In the Elko Quadrangle, intrusive rocks of granitic to granodiorite composition are commonly in contact with carbonate sediments. Depending on mode of intrusive emplacement, on the reactivity of carbonate host, on intrusive and host-rock composition, and on heat content and availability of aqueous solutions, the resulting contact metasomatic uranium deposits develop as a result of replacement reactions between uraniferous magmatic emanations or in-situ remobilization and concentration of uranium in a stable host rock in response to late stages of magmatic activity (intrusion - thermal metamorphism - metasomatism). All contact metasomatic occurrences are associated with copper, tungsten, gold, silver, lead, or zinc mineralization. Copper-bearing contact rocks commonly have anomalous radioactivity and/or uranium concentrations. Andradite garnet, epidote, iron and copper oxides and sulfides, calcite, and quartz are developed in host limestones in contact with monzonite to quartz monzonite (locally porphyritic) intrusive rocks.

Contact deposits looked at and sampled include Jacobs Peak stock, Harrison Pass pluton, Ferber stock, Kingsley stock, White Horse Pass pluton, and the Melrose stock (App. D). Portions of the Melrose and Bullion stocks could not be examined because of limited access due to mining or exploration

activity. Most contact rocks are of high sulfide content and are now oxidized to porous iron and manganese oxides and calc-silicate minerals.

Radiometrics are commonly very low (less than 150 cps), usually less than the adjacent granitic rocks. Numerous rock samples were collected for assay, including intrusive, unaltered host, and metasomatized rocks. Thirteen samples of unfavorable contact metasomatic rocks averaged 23.7 ppm U_3O_8. Of these the most interesting include the White Horse area (MEY 236, 64 ppm), Melrose (MEY 248, 33 ppm), Kingsley (MEY 254, 55 ppm), and Ferber area (MEY 122, 100 ppm). Too few samples as a result of very late assay returns prevented further followup work. Appendix D lists average uranium contents of the associated intrusive rocks. From these results, it is obvious that the Ferber and Melrose stocks are enriched, and the Kingsley and White Horse intrusives have a relatively low uranium content. Thus, enrichment of metasomatic rocks does not appear to be directly proportional to the degree of enrichment in the associated intrusive rocks.

Although uranium concentration has occurred, these deposits cannot be considered favorable for the minimum tonnage because of the relatively small size of metasomatized bodies of rock and relatively low uranium concentrations in most samples.

ANATECTIC ROCKS

The East Humboldt and northern Ruby Mountains are made up principally of high-grade metamorphic rocks as described by Howard (1966), Sharp (1939, 1942), and Snelson (1957). These rocks exhibit many characteristics that fit criteria of the anatectic class (Class 380).

In general, the rocks consist of high-grade metamorphics that include quartz diorite to leucogranite gneisses, quartzites, carbonates, and lime-silicate rocks exhibiting schistose, mylonitic, and granulitic textures. Abundant pegmatite and aplite dikes of silicic composition are associated with the metamorphic sequence. The geology is further described under geologic setting. Howard (1966), Smith and Howard (1977), and Howard and others (1979) have mapped a series of thrust faults and recumbent folds in the central Ruby Mountains. Mesozoic(?) quartz monzonite and granodiorite gneiss were emplaced during folding and metamorphism. Subsequent metamorphism and migmatization resulted from intrusion of the Jurassic pegmatitic granite.

Lithologic, mineralogic, textural, and structural parameters of the anatectic class closely correspond to the East Humboldt - Ruby area. Pegmatite dikes, lesser alaskite dikes, and the occurrence of synkinematic alaskite and biotite granite are common; but none are highly uraniferous.

Ground radiometrics have not identified any large anomalies, and assays do not exceed 12 ppm U_3O_8. All anomalous samples come from the Lamoille Canyon area from rocks ranging in composition from quartzofeldspathic to granodiorite gneiss. The uranium content ranges from 4 to 12 ppm U_3O_8 and averages 7.0 ppm for 5 samples. All other samples were of metamorphosed Precambrian-Paleozoic sediments averaging 1 ppm U_3O_8. Rocks with relatively anomalous uranium concentrations are considered poor source rocks

because of their small aerial and volumetric proportions. They are not sufficiently enriched in uranium to be considered favorable for anatectic deposits.

PEGMATITIC ROCKS

Intense pegmatitic-aplitic diking occurs in the central Ruby Mountains in Gilbert, Mica, and Dawley Canyons. Pegmatites in these areas were mapped and described for their beryllium potential by Olson and Hinrichs (1960).

The pegmatite dikes crop out within Cretaceous biotite-muscovite granite, Jurassic pegmatite granite, and upper Precambrian-lower Paleozoic metasediments that consist of schists and quartzites. In Dawley Canyon, more than 350 pegmatite dikes crop out in a 2.6-mi^2 area (as mapped by Olson and Hinrichs, 1960). The dikes strike north, have steep dips, attain widths up to 55 ft, and are exposed to lengths of 2,200 ft. Dikes are emplaced along schistosity planes in metasediments and along fracture-joint sets in metasedimentary and granitic rocks. Both zoned and unzoned dikes occur and exhibit varying zonal development and mineralogic, textural, and spatial characteristics. In addition to common rock-forming silicates, hematite, garnet, beryl, columbite-tantalite, autunite, and phenakite are reported by Olson and Hinrichs (1960).

A detailed examination of the major and many of the minor pegmatites and aplite dikes was accomplished by ground radiometric and rock-sampling techniques. All radiometric surveys of the dikes and surrounding granitic-metasedimentary rocks were low. Ten major and/or radiometrically anomalous dikes were sampled. Most dikes sampled are well zoned, beryl bearing, and contain rare-earth oxide minerals. All dikes sampled contain less than 10 ppm uranium (average 2.7 ppm) and are considered unfavorable. One dike reportedly contained autunite. Examination of the dike has disclosed no visible autunite. In light of the low radioactivity and poor sample results (MEY 144, 2 ppm), it is considered non-uraniferous.

The pegmatite dikes have many characteristics of uraniferous dikes; although, radiometrics and sample results have not delineated any anomalously uraniferous areas.

CARBONACEOUS SHALES

Organic-rich shales (lignite, coal, and carbonaceous) of Class 210 crop out in numerous localities in the northwest quarter of the quadrangle. Oil shale, interbedded lignite, and carbonaceous shales are common constituents of the Oligocene-Eocene Elko Formation of Smith and Ketner (1976). The most prominent outcrops of these organic-rich shales are in the southern Adobe Range northwest of Elko, the Elko Hills southeast of Elko, and the east side of the Pinon Range southwest of Elko. The Elko Formation unconformably overlies the Mississippian Diamond Peak Formation in most areas and is unconformably overlain by rhyolitic to andesitic volcanics (Smith and Ketner, 1976).

Compositionally the Elko Formation is composed of thin-bedded limestone, laminated paper shale, and tuff. The most common lithologies of interest include laminated carbonaceous oil-bearing paper shales and fossilferous and interlayered shales and marls in the Pinon Range (Smith and Ketner, 1976); brown to black carbonaceous oil and lignitic shales interbedded with tuffaceous shales, cherts, and siltstones in the Elko Hills (Winchester, 1923); and highly fossiliferous gray-black carbonaceous shales interbedded with sandstones, conglomerates, and limestones in the southern Adobe Range (Ketner, 1976). The Elko Formation was deposited in quiet water of a relatively large lake basin (Smith and Ketner, 1976). Winchester (1923) has correlated the organic-rich beds with the Eocene Green River Formation of Wyoming, Colorado, and Utah; but Smith and Ketner (1976) indicate a somewhat younger age for the lower and middle Eocene Green River Formation that is based on potassium-argon dating.

The Elko Formation meets the genetic criteria of Class 210 and contains rocks capable of carrying high concentrations of uranium (McKelvey, 1955). Uraniferous rocks of this type commonly can contain 50-100 ppm U_3O_8; although, all localities sampled in the Elko Quadrangle contained 9 ppm U_3O_8 or less. All radiometric traverses were relatively low, and analyzed samples ranged from 1 to 9 ppm U_3O_8. Petrologic and assay results indicate that as organic material increases so does the uranium content. The exposed areas sampled are thought to be representative of the formation; however, unexposed areas overlain by thick sections of Tertiary volcanic and volcanic-sedimentary rocks could contain higher concentrations of uranium than those observed.

MARINE BLACK SHALES

Paleozoic marine black shales (Class 130) that crop out in the Elko Quadrangle include the Upper Devonian-Lower Mississippian Pilot Shale and the Upper Mississippian Chainman Shale. The Pilot Shale crops out along the eastern border of the quadrangle in the Leppy Hills and the Goshute Range. This shale is typically thin bedded, fine grained, fissile, calcareous, and dark gray to black on a fresh surface. The Pilot Shale is overlain by Joana Limestone, which is overlain by the Chainman Shale. Much of the Chainman consists of black shale with local interbeds of brownish-red sandstone. The Chainman Shale is widespread throughout the quadrangle; although, most exposures are concentrated in the Carlin-Pinon and Toano-Goshute Ranges.

Black shales contain more uranium than the average sedimentary rock but few contain more than 50 ppm U_3O_8. In general, the uranium content increases. Black shales in the Elko Quadrangle lack many of the important characteristics associated with uraniferous black shales. The Pilot and Chainman Formations lack very high concentrations of organic material, pyrite, and phosphatic material; and they have relatively high carbonate concentrations and appear to have a high clastic fraction rather than a predominance of clays. Other factors, such as trace-element contents and variations in abundance of uranium over large areas, have not been evaluated. Radiometric traverses and uranium sample results indicate that neither of the formations is anomalously uraniferous. The samples represent areas of higher than average radiometrics within the formation. Nine samples were collected and averaged about 1 ppm U_3O_8. The Chainman Shale has an average uranium

content of 1.5 ppm, and the Pilot Shale has 0.6 ppm U_3O_8. In the Newark Pass area of White Pine County, the Pilot Formation was studied by Duncan (1953) who indicated the formation was weakly radioactive. Two rock samples taken from the base and top of the formation contain 20 ppm and 10 ppm U_3O_8, respectively. Our samples of the Pilot Shale are well below the values of the Newark Pass area to the south.

LIMESTONES

Carbonate rocks in the Elko Quadrangle, consisting of limestone and dolomite, are considered unfavorable for Class 230 uranium deposits. A large portion of the Elko Quadrangle is composed of carbonate rocks and has thick stratigraphic sections and major ranges that include the southern Ruby, Pequop, Toano-Goshute, and Cherry Creek Ranges. During this study, numerous radiometric traverses (airborne and ground) were made across all major stratigraphic units and mountain ranges so that all carbonate formations were examined. In addition to radiometric surveys, numerous rock samples were collected as spot checks.

Carbonate rocks are the least uraniferous rocks of the Earth's crust: these rocks seldom contain as much as 4 ppm U_3O_8 (Bell, 1963). To contain more than this amount, the rocks must either be impure, or the uranium must be epigenetic in nature.

Impure carbonate rocks commonly occur in the quadrangle and commonly contain organic material or marine apatite as impurities. Both of these impurities can act as uranium concentrating agents during syngenetic deposition by the substitution of uranium in the apatite lattice or through reaction with organic matter (absorption or reaction-depostition). Most samples have a low uranium content, and this uranium is probably of an epigenetic nature. The high concentrations of carbonate prevent precipitation or absorption of uranium even in a highly organic or reducing environment. About 60 samples of limestones were taken, most of which contained 1 ppm or less; although, some were in the 5-6 ppm U_3O_8 range. The overall average uranium content was about 1.25 ppm U_3O_8 for all carbonate formations sampled. Rocks of the Permian Park City Group limestones (2.4 ppm) and the Tertiary limestone of the Dixie Flat area (2.5 ppm) have slightly higher averages.

Dark-gray, silicified, bioclastic limestones of the Mississippian Diamond Peak Formation crop out on the west side of Diamond Peak in the Diamond Mountains (Pl. 14). Six rock samples were taken of this unit along and across strike. They ranged from 1 to 10 ppm U_3O_8 and averaged 3 ppm U_3O_8. This is the most anomalous uranium content in the carbonate rocks in the quadrangle. The higher-than-average concentration may be due to late silicification (uranium moving with silica) by ground-water movement and reduction by the abundant organic (highly fossilferous) material in the limestone. Recrystallization of the sediments into pelitic and calc-silicate hornfels and marbles occurs near the Jacobs Peak granodiorite stock. The highest uranium contents are in silicified, highly organic, non-metamorphosed dark limestones of a discontinuous nature.

SANDSTONES

Sandstone-type environments (Class 240) occur in the Elko Quadrangle and include Triassic-Jurassic sandstones and conglomerates and Mississippian-Pennsylvanian clastics and minor limestones.

The Triassic-Jurassic rocks include the Dinwoody shale and limestone, Thaynes limestone and shale, Nugget sandstone, and the Chinle mudstone, limestone, shale, and conglomerate. All formations crop out in the Currie area and in the southern Pequop Range as discussed by Nelson (1956) and Sirkin (1970). The Shinarump Conglomerate member of the Chinle Formation and the Nugget Sandstone appear to be the best host environments. All formations were radiometrically traversed and representative samples were collected.

The Nugget Sandstone is the probable correlative of the Currie Sandstone (Sirkin, 1970) and consists of a thick, massive, uniform, mature quartz arenite deposited in a subaqueous environment that has been cemented with silica and carbonate. The permeability is very low. Based on petrology and low radiometric and sample assay data (high of 2 ppm U_3O_8), this unit appears unfavorable for uranium deposition.

The Shinarump Conglomerate is a known uranium producer in Utah and Arizona; there, it occurs as channel-fill sandstones and conglomerates interbedded with siltstones and mudstones (Young, 1964). Clastic material includes quartz, chert, quartzite, limestone, etc. (Thaden and others, 1964). At Currie, the Shinarump has petrologic, textural, and stratigraphic relations similar to those in Utah and Arizona and is radiometrically more anomalous than accompanying sedimentary rocks. Areal distribution of the conglomerate is very limited. The only rock sample collected yielded just 1 ppm U_3O_8.

The Dinwoody and Thaynes formations are radiometrically low and all rock samples collected averaged 1 ppm U_3O_8.

The Diamond Peak and Diamond Peak - Chainman (undivided) Formations are extensive in the western third of the quadrangle. The type section in the Diamond Mountains was described by Dott (1955) and by Brew (1964) and consists of interbedded siltstones, conglomerates, limestones, sandstones, and claystones. Reddish-brown cobble conglomerates are very diagnostic of the formation. Silica-cemented chert, quartzite, and sandstone clasts range from silt to boulder size. Local cross-bedding and channel structures occur. All of the members appear to be oxidized (reddish color), and reductants (pyrite, organics) are not present. Brew (1964) describes pyritic beds in Eureka County, but most beds have been leached or oxidized to limonite. The differential permeability within the section locally may provide suitable aquifers for uraniferous ground water, but significant reductants are lacking. All radiometric traverses across the formation revealed low uranium content. Representative samples contained uranium concentrations of 3 ppm or less and averaged only 1.2 ppm U_3O_8.

PHOSPHORITES

In the Elko Quadrangle, there are two areas of sedimentary phosphatic rock outcrops: the southern Pequop Mountains and the southern Adobe Range and

Elko Hills. In the Pequop Mountains, phosphorite is exposed along the range crest and along the lower east slope. The beds are within the upper Paleozoic (Permian) section of limestone, cherts, and phosphatic rocks tentively correlated with the Phosphoria Formation of Utah and Idaho (Snelson, 1955). The Phosphoria of the Pequop Mountains can be divided into three members: 1) a lower black chert and mudstone unit with oolitic phosphate; 2) a middle limestone and brown-black chert; and, 3) an upper, gray brachipod limestone (Snelson, 1955). Underlying the Phosphoria are Permian limestones of the Kaibab Formation which is overlain by the Triassic Dinwoody and Thaynes Formations.

The phosphatic member consists of black and brown chert, black mudstone and some bluish-black, thin-bedded oolitic phosphatic rock. Phosphate beds are nearly vertical and extend along strike for about 10 mi. Smith (1976) reports up to 36.2 ft of 10.5% P_2O_5. Phosphate beds of the Phosphoria Formation are known to contain anomalous quantities of at least 20 trace elements and a uranium content between 5 and 500 ppm (Gulbrandson, 1966). Uranium content of sampled phosphorites is negligible, with a high of 2 ppm U_3O_8. A water sample (MEY 690) had only 2.8 ppb U_3O_8. These results, in conjunction with low radiometrics, indicate that these rocks are relatively non-uraniferous, unlike their Phosphoria equivalents.

Phosphatic rocks of the Adobe Range and Elko Hills are described by Ketner (1970 and 1979). A thick sequence of Permian rocks with abundant phosphatic beds closely resemble and are correlative with the Phosphoria Formation (Ketner, 1979). The beds are composed of calcarenites, siltstones, chert, and phosphatic beds concentrated in the uppermost portion of the section. These beds were deposited in a shallow marine environment of a partially enclosed epicontinental seaway. Phosphate commonly occurs as oolitic to large nodular pellets and pelletal aggregates. The average phosphate content is 2.3% P_2O_5; whereas, underlying Permian beds contain only 0.5% P_2O_5. Uranium content of these beds averages 2.5 ppm U_3O_8, with highs of 3 ppm U_3O_8. The beds are highly phosphatic but not anomalously uraniferous.

UNEVALUATED ENVIRONMENTS

In the Elko Quadrangle, unevaluated environments include partially closed or closed basins surrounded by uraniferous potential source rocks, and down-dip extensions of the uraniferous portions of the Humboldt Formation. A brief discussion of geologic relations and criteria for classification as unevaluated follows. Because of lack of useful subsurface data, adequate evaluations of these environments were not realized. Available information indicates that further consideration of these environments may be warranted.

The Elko Quadrangle contains 23 intermountane basins that cover nearly 45% of the total area. In Nevada, basins of various depths are a result of predominantly north-south trending horst and graben structures developed during Tertiary block faulting and subsequent infilling with volcanic, clastic carbonate, and alluvial material. During specific periods throughout the Tertiary, volcanic tuffs, interbedded clastic and carbonate sediments, tuffaceous sediments, and organic-rich shales filled these basins. The Indian

Well, Humboldt, and Elko Formations are examples of this infilling. Subsequent diagenetic alteration of volcanic tuffaceous rocks of silicic composition and ground-water circulation may provide a release and movement mechanism for uranium initially incorporated in the volcanic materials. Organic shales (carbonaceous and petroliferous) may provide a locus for reduction and concentration of uranium from ground-water solution. Surface exposures of organic-rich shales contain low concentrations of uranium, possibly due to leaching or limited interaction with uraniferous ground water. At depth, organic shales overlain by abundant and leachable tuffaceous material may have a significant uranium potential.

Results from soil and water samples in areas of abundant volcanic material indicate that uranium is being moved in the ground water and occurs as detrital material resulting from the breakdown of tuffs.

Ground-water leaching of voluminous amounts of detritus being shed from granite and metamorphic terrains adjacent to basins provided a possible uranium concentrating system. Intrusive bodies such as the Harrison Pass pluton and associated granite bodies, Precambrian to lower Paleozoic metamorphics of the Ruby Mountains, Delcer - West Buttes, Northern Toano Range, and Melrose stock of the Dolly Varden Mountains are all relatively uraniferous. Detrital material from these masses has flooded the adjacent basins and, in addition to volcanic detritus, could become a substantial source of uranium under proper conditions. Highly anomalous stream-sediment (up to 51 ppm U_3O_8), soil, and water (up to 16 ppb) samples have been collected in the Ruby, Huntington, Lamoille, and Mound Valleys on the east and west flanks of the Ruby Mountains. The only known uranium occurrences are at the north end of Huntington Valley and around the Delcer - West Buttes; although, samples indicate an overall higher uranium concentration in these areas. It is impossible to evaluate these basins further with the methods available to us.

The two occurrences (1 and 2) in the Miocene Humboldt Formation are indications that portions of this formation may be quite uraniferous. At this time, these are the only two areas of anomalous uranium concentrations identified within the Humboldt Formation in the Elko Quadrangle. Initial sample data indicate that some of the tuffaceous sediments and vitric tuffs contain up to 440 ppm U_3O_8, and many samples are in the 100 ppm U_3O_8 range. In both of the occurrences, the uraniferous sediments dip beneath Quaternary alluvium or are covered by other non-uraniferous portions of the Humboldt Formation such as limestones and non-tuffaceous clastic material. Further surface exposures were looked for and identified in other areas with only limited success. A measured, but incomplete, stratigraphic section (Smith and Ketner, 1976) lies along the east bank of Huntington Creek Valley about 1.25 mi east of occurrence 2. The along-strike extension of occurence 2 falls lower, stratigraphically, than the lowest exposed portion of the measured section; thus, the strike length of these beds is undetermined. A portion of the same measured section appears roughly correlative with the tuffaceous material of occurrence 1, which lies 4 mi to the northeast; however, no uranium anomalies were identified in the measured section. Because of poor exposure, lack of consolidated outcrops, and abundant gravel and other alluvial cover, methods in addition to ground radiometrics and sampling are required for the identification of possible extension of known occurrences or discoveries of other uraniferous bodies in this formation.

RECOMMENDATIONS TO IMPROVE EVALUATIONS

Improvement of the present evaluation for uranium resources of the Elko Quadrangle will require more mapping and sampling and, most importantly, drilling.

Unquestionably, the basins need the most followup work in order to establish if they host a potential uranium resource. Clearly, in the basin environment, sampling by drilling methods will be the most instructive method of evaluation. The initial sampling of possible igneous source rocks has been accomplished. Limited soil, stream-sediment, and water sampling has been done. Followup sampling by similar methods may help to better define areas of highest uranium movement and concentration. Track Etch® surveys followed by drilling programs should be conducted in areas of anomalous uranium concentration. Stratigraphic data, in addition to radiometric and chemical-uranium assay data obtained from drill holes, will help in evaluating these basins.

The uranium occurrences within the Humboldt Formation will take a substantial amount of further work for proper evaluation. Stratigraphic relations within the Humboldt Formation in the favorable areas must be worked out in detail, and further detailed geologic mapping must be done. When geologic and stratigraphic relations are well understood, successful exploration of the formation as a whole can be accomplished. In and around the anomalies, surface exposures are usually poor; therefore, areas down dip and along strike extensions of the mineralized zones will have to be tested by Track Etch® surveys and possibly followed by drilling programs. Here again, stratigraphic information obtained from drilling, coupled with information on uranium concentrations encountered, will help direct further exploration and evaluation of this formation.

Because of very slow sample turnaround time, most assay and other analytical data were not received until well into the writing phase. These delays precluded further sample followup (field checking and subsequent sampling) of areas with anomalous results. After looking through all sample data, it is apparent that the contact metasomatic and allogenic environments may warrant further work.

The contact metasomatic environment is many times overprinted by allogenic uranium concentrations at locations where Mesozoic granite intrusives are in contact with carbonate sediments. Sample results from contact zones around the Delcer - West Buttes and the Melrose stock contain uranium in anomalous quantities. Samples from these zones contain up to 500 ppm uranium, and many samples contain in the vicinity of 50-100 ppm. Extensions of these and similar unidentified zones around felsic stocks should be looked for and sampled in detail. Mapping these zones will help establish size and spatial relationships. These environments may not prove to be a potential resource because of their small size and sporadic nature; however, the anomalous uranium concentrations warrant further investigation.

Numerous sediment samples on both east and west sides of the Ruby Mountains (Franklin Lake and Jiggs areas, respectively) have anomalously high concentrations of uranium. Most material sampled is detritus shed from the Ruby igneous-metamorphic terrain. It should be determined how much of the

uranium is leachable and how much is in refractory minerals. These samples may represent alluvial placer concentrations of refractory minerals derived from the Ruby Mountains. Data obtained from drill holes in critical areas should answer some of the remaining questions. Areas where further work should be concentrated include Ruby Valley, Mound Valley, Huntington Creek Valley, and Steptoe and Antelope Valleys. The selection of these areas is based on all available information in conjunction with the results of this study.

Data generated from the aerial radiometric and magnetic reconnaissance survey conducted by Geo-Life International, Inc., were received after the field work had been completed. Some anomalies, as determined by this survey, may warrant field checking if further work is to be done in this quadrangle.

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